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DEPARTMENT OF DEFENSE
U.S. ATOMIC ENERGY COMMISSION

Project

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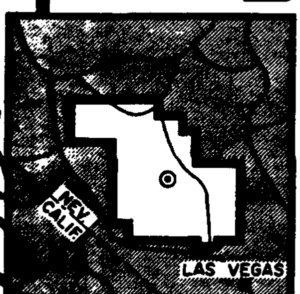
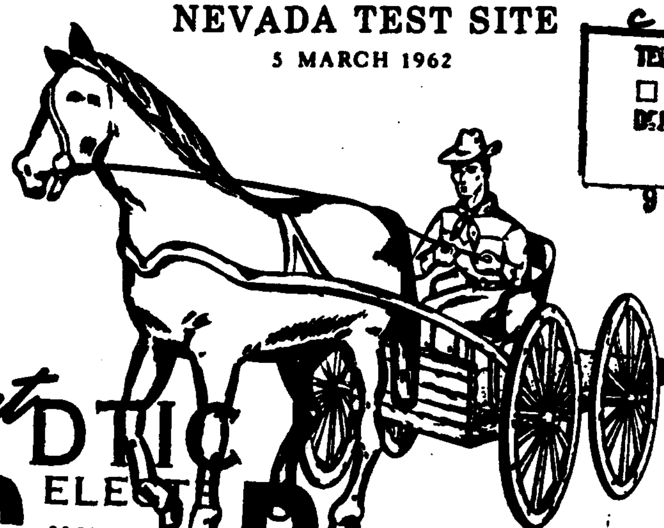
DANNY BOY

NEVADA TEST SITE

5 MARCH 1962





Final Report

Project 1.1a

LONG-RANGE AIR-BLAST MEASUREMENTS AND INTERPRETATIONS

Jack W. Reed
SANDIA CORPORATION

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PROJECT DANNY BOY

POR (WT) 1809-1

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PROJECT 1.1a

LONG-RANGE AIR-BLAST MEASUREMENTS AND INTERPRETATIONS

Jack W. Reed
Sandia Corporation

August 1963

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ABSTRACT

Low-pressure air blast was measured for Project Danny Boy out to distances of 240 kilometers in order, primarily, to determine the attenuation caused by the hard rock environment of the shot and to compare results from both nuclear and HE shots in other media. Nine microbarograph stations were operated. Communications problems and strong local winds reduced the number of signal correlation points. Air-blast pressures, both close-in and far-out, were smaller than were expected, based on past experience with underground HE shots. Distant off-site recordings indicated that blast pressure amplitudes from the Danny Boy shot averaged only 14 percent as large as would have been received from a shot having the same nuclear yield, free-air-burst.

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Chapter 1 [redacted]

INTRODUCTION

1.1 Shot Description

Project Danny Boy was a nuclear device of 420 tons yield burst at 33.5 meters depth in the basalt rock of Area 18, Nevada Test Site. The shot was fired at 1015 PST, March 5, 1962.

1.2 Objectives

Low-pressure air blast was measured out to 240 kilometers range on the test in order to:

(1) determine attenuation caused by bursting in a hard rock underground environment;

(2) determine whether Projects Stagecoach and Scooter results, i.e., that attenuation decreases with increased yield at constant scaled depth of burst (DOB) in desert alluvium, are also applicable in hard rock;

(3) determine whether underground nuclear and high-explosive (HE) bursts give comparable air-blast effects; and

(4) produce further confirmation for sound-ray calculation techniques, as computed from rocket high-altitude wind instruments, when used at ranges beyond 100 miles.

1.3 Background

Blast propagated to and beyond 160 km from the buried Teapot Ess shot at Nevada Test Site (NTS) in 1955 gave pressure amplitudes having differences of little consequence from those which would have been expected from a surface burst of the same yield.[1] Close-in high pressure measurements showed considerable blast reduction caused by shot burial.[2] If distant blasts from underground cratering or excavation shots are only slightly muffled, large Plowshare yields can cause considerable distant damage and adverse public reaction.

Distant blast measurements have been made on Plowshare Projects Stagecoach, Buckboard, and Scooter to develop understanding of this blast attenuation by shot burial at scaled depths which produce craters.[3-5] The blast transmission factor, defined here as the ratio of observed blast-wave pressure to that expected at the same range from a burst of the same yield in free air, increases with distance to long range. This has been verified by every Plowshare microbarograph experiment (see Fig. 1.1).

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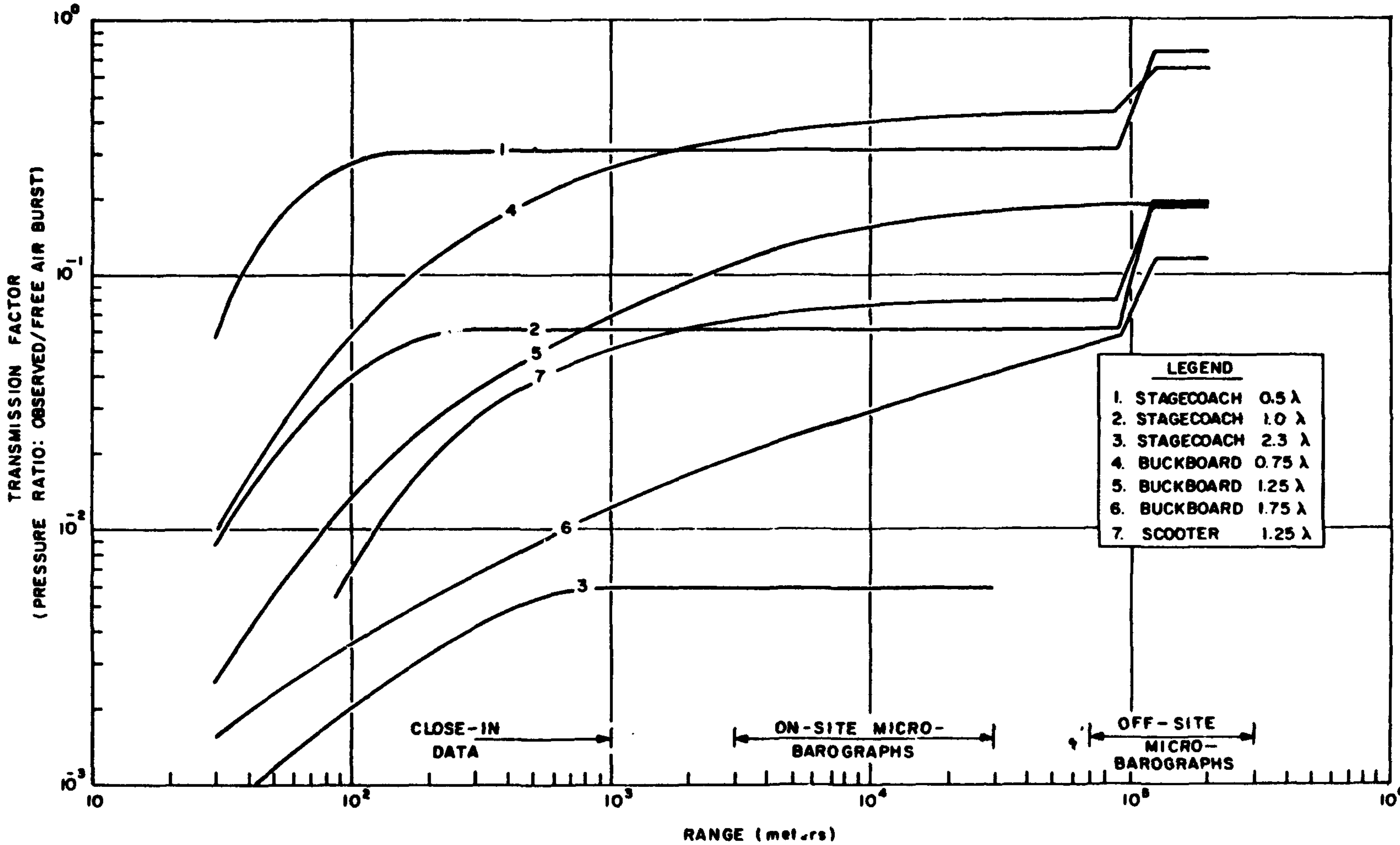

Fig. 1.1 Air blast transmitted from Plowshare underground high-explosive shots at Nevada Test Site.

A comparison of Stagecoach and Buckboard data, for 20-ton HE bursts in desert alluvium and volcanic basalt demonstrated that more distant air blast was transmitted from a hard rock environment at constant scaled DOB. Scooter, 500-ton HE, and Stagecoach bursts in alluvium proved that there was greater transmission for the larger yield from constant scaled DOB.

Each data point from these few experiments has rather large proportional errors caused by inconstant atmospheric sound propagation to great distances. Resulting transmission factor uncertainties cause an uncertainty of more than an order of magnitude in establishing safe yield limits in extrapolation to large excavation projects. Obviously, with careful selection of sites, season, and weather conditions, some very large cratering (or even surface burst) projects may be conducted without significant damage, but if useful projects are to be pursued with optimum economy and minimum weather delay, better understood and more accurate predictions must be available. To assure that no opportunity is missed for refining blast-safety prediction techniques, all large Plowshare or other cratering experiments should be monitored by distant blast-pressure observations.

Further experience with air-blast transmission factors for underground bursts has been obtained from recording shots buried at depths which produce no directly blown-out cratering. The Plumbbob Rainier event in 1957 and the Hardtack II underground tests in 1958, all burst in volcanic tuff (a soft, light, welded ash), appeared to emit significant air-pressure waves.[6] There was no basis for comparison of these signals with air bursts except by climatology, i.e., the average seasonal propagation amplitude scaled from all previous Nevada tests.[7]

In Operation Nougat at NTS in 1961 and 1962, transmission experiments were performed on several shots, but with limited success.[8] Microbarograph participation has consistently been impaired by wind storms, as was the case on Project Gnome at Carlsbad, New Mexico, in December 1961.[9] The only results obtained were tentative and qualitative. Nuclear bursts buried deep in alluvium seemed to produce much less air-blast transmission than those in equivalent depths in tuff. The one Nougat recording from a nuclear shot in tuff is not obviously inconsistent with estimated transmissions from Rainier and Hardtack II. Finally, the Hardhat burst in granite appears to have transmitted less air blast than was expected from Buckboard and tuff experience.

During 1960 Plowshare experiments at NTS, the first attempts were made to calculate ozonosphere blast propagations from rocket measurements of winds in the 30- to 45-km MSL layer. Rocket sounding techniques were developed for use during Hardtack high-altitude measurements, but were never available for full-scale test blast predictions at NTS. Results from Plowshare calculations were encouraging, but more experience is necessary before these predictions can be made with the confidence necessary for full-scale blast-safety requirements. These calculations have been verified many times for troposphere jet-stream-ducted blasts, but there are some added considerations for propagations along the extremely low-air-density high-altitude ozonosphere paths which are not adequately understood.

1.4 Theory

Air blast propagated from nuclear and HE bursts above ground has been documented in great detail in the strong shock region. Some different opinions persist about overpressure-distance decay beyond the 300-mb region, but they are not of fundamental importance in long range prediction. From past experience it is here contended that the overpressure-distance curve calculated years ago at Los Alamos as IBM Problem M[10] provides a better reference standard at low pressures than does the empirical curve used in *The Effects of Nuclear Weapons*.[11] Actual nuclear-test data obtained at low-pressure measurement distances appear to be biased by refraction in the real atmosphere environment. They would not be duplicated in a truly homogeneous atmosphere, if one of suitable dimension were available.

Grounds for this contention are found in data, as yet unpublished, from vertical propagations (parallel to atmospheric sound-velocity gradients and thus not bent by refraction) of blast from HE tests. First a series of 454-gram HE experiments was fired at Sandia Laboratory at heights from 30 to 150 meters above a pressure gage array to show the appropriate pressure-distance curve extension to 7 mb. In DASA Project Banshee, three 227-kg HE shots were fired 24 km over White Sands Missile Range to give, among other things, unrefracted blast pressures at 40 microbars (μb). Both sets of data fall on a pressure-distance curve drawn from the end of IBM Problem M calculations at 25.5 mb and 2740 m, with overpressure decaying in inverse proportion to the 1.2 power of distance or

$$\Delta p \sim R^{-1.2}, \qquad (1.1)$$

where Δp is overpressure and R is distance. This recommended standard homogeneous atmosphere curve is shown in Fig. 1.2 for a 1-kiloton nuclear free-air burst at sea level. Overpressures appear to decay somewhat faster than expected for spherical, infitesimal amplitude, acoustic waves.

A standard pressure-distance curve is scaled to both different yields and gage-level ambient atmospheric pressures to predict a curve for a particular shot by applying the two equations

$$\Delta p' = \Delta p(p'/p), \quad (1.2)$$

and

$$R' = R(W'p/Wp')^{1/3} \quad (1.3)$$

where W is yield, p is atmospheric pressure at the blast gage altitude, unprimed quantities are standard values, and primed quantities are new values for specified conditions. In the extended low-pressure region where $\Delta p \sim R^{-1.2}$, it follows that at constant range,

$$\Delta p \sim W^{0.4}p^{0.6}. \quad (1.4)$$

Air-burst calibration shots were fired to show actual atmospheric propagation conditions as near Danny Boy in space and time as operations would permit. It was postulated that results could be scaled to predict pressures from Danny Boy if fired as a free air burst. Pressure amplitudes for Danny Boy, divided by this scaled prediction, would give the air-blast transmission coefficient.

Calibration shots were 1.2-ton (1090 kg) HE, burst 4.56 meters above ground on a wooden platform as shown in Fig. 1.3. At overpressures below 200 mb, effects of the platform and nonspherical charge were found to be negligible. At this scaled height of burst (HOB), 1.12 λ*, Mach stem effects cause blast overpressures which appear to have come from 1.76 W yield. This had been determined in Sandia HE experiments scaled by Vortman and Shreve[12] to 6.1 meters from 454-gram HE shots. Measurements at 190 km from 2.5-ton (2270 kg) HE shots at Sandia in 1961 verify that close-in height-of-burst effects are propagated to large distances.[13]

A predicted sea level (1000 mb, per IBM Problem M) overpressure-distance curve for calibration shots on Danny Boy would then be scaled for range or

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*λ units are feet/(lbs HE)$^{1/3}$, 0.396 meters/(kgs HE)$^{1/3}$, 100's feet/(kts NE)$^{1/3}$, or 3.8 meters/(ton HE)$^{1/3}$.

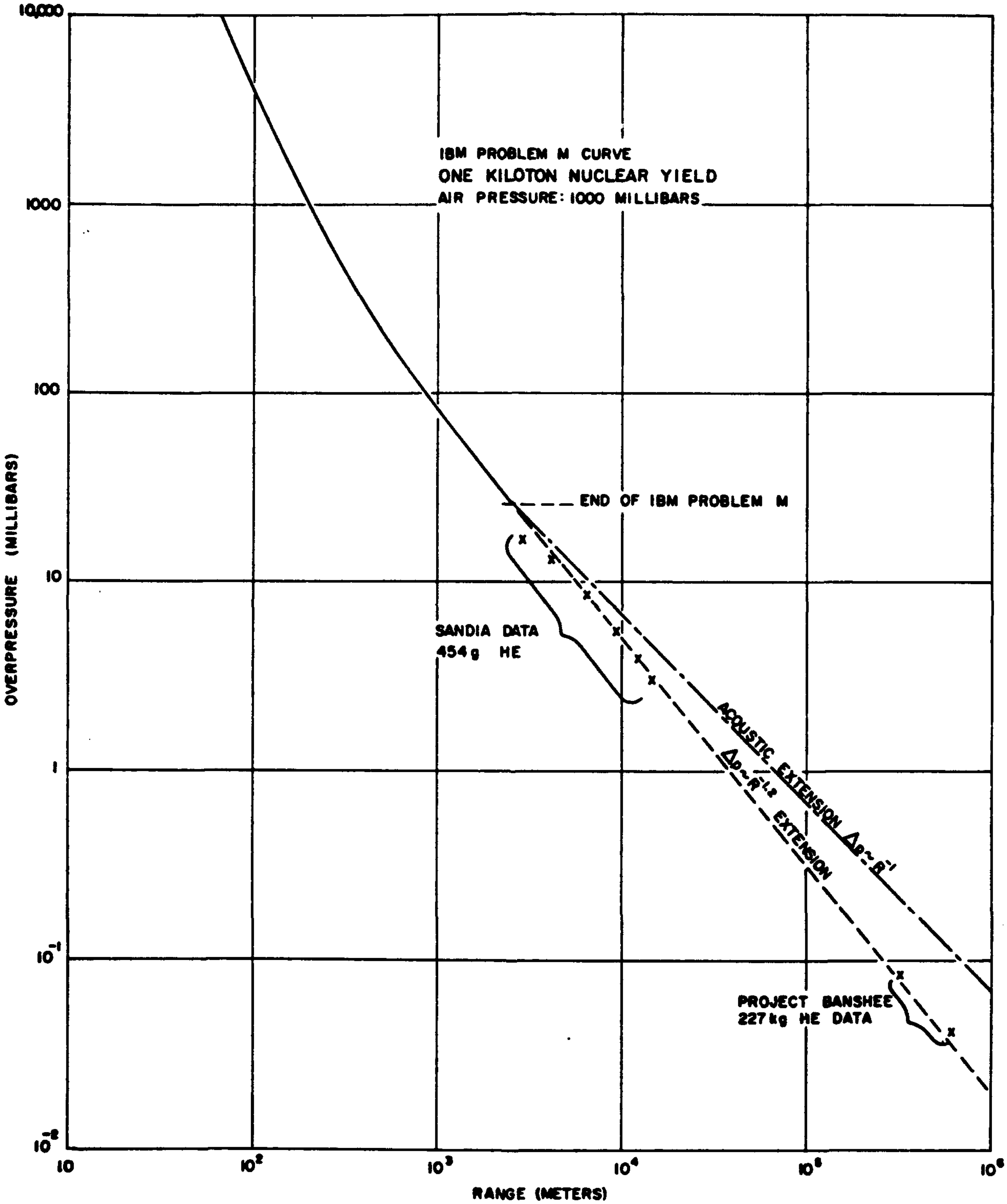

Fig. 1.2 Standard explosive overpressure-distance curve.

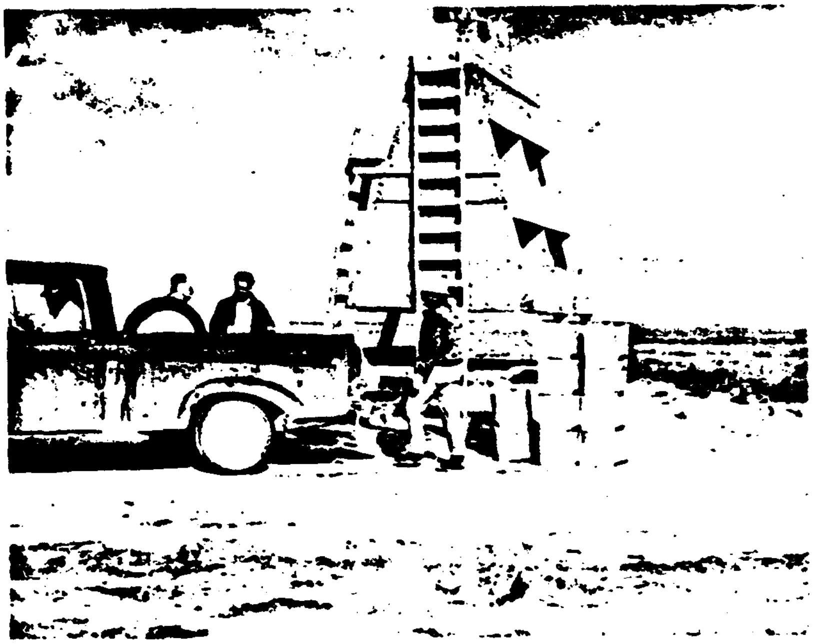

Fig. 1.3 Calibration shot platform for 1.2-ton high explosives.

distance, assuming that 1-ton HE is equivalent to 2-ton nuclear explosive (NE) in blast production, by

$$R_C' = R[(2)(1.76)(1.2)/(1000)]^{1/3} = 0.1616\ R. \qquad (1.5)$$

Danny Boy, with 420-ton NE yield, free-air-burst, would have the same sea level blast pressures at distances scaled by

$$R_D' = R[(420)/(1000)]^{1/3} = 0.749\ R. \qquad (1.6)$$

Overpressure-distance curves for both the calibration shots and a free-air-burst Danny Boy device in a homogeneous atmosphere are shown in Fig. 1.4 for the ranges covered by microbarograph measurements.

Two alternative assumptions were considered in predicting actual Danny Boy air-blast pressures. First, it was assumed that nuclear devices burst underground would produce waves equal to those of HE bursts of the same Yield. This

follows from the concept that radiant energy from an underground nuclear burst cannot escape. In nuclear air bursts this energy does escape, to leave only half of the total yield available for shock formation. Danny Boy burial at 33.5 meters would thus be at a scaled depth of burst of 1.166 λ. Reference to Fig. 1.1 at 10^4 meters shows that the Scooter air blast was about 2.2 times what would have been predicted from Stagecoach data. Buckboard transmissions interpolate for 1.166 λ to about 0.175; multiplication by the yield effect of Scooter (comparable to the Danny Boy yield) gives a transmission prediction of 0.39. This gives the dashed pressure-distance curve in Fig. 1.4, labeled 100-percent yield factor, for a Danny Boy prediction.

A second assumption may be made, namely, that nuclear burst effects are equivalent to those from half the stated yield in HE. Obviously, losses cannot be attributed to radiations. There are, however, mechanisms such as rock vaporization, lack of gaseous mass to push out an explosion wave and crater, etc., which may be used to explain the losses. No further explanation is appropriate here. In this case, burst would have been at 1.457 λ, where interpolation from Buckboard shows a transmission factor of 0.097 and the Scooter-to-Stagecoach yield effect raises the predicted transmission factor for Danny Boy to 0.215.

These predictions indicate that at intermediate constant ranges, Danny Boy pressures would have 2.45 (assumption 1) or 1.35 (assumption 2) times the amplitudes recorded from HE calibration shots. Pressures would be relatively lower close-in and higher at longer ranges in the ozonosphere sound ring beyond 10^5 meters.

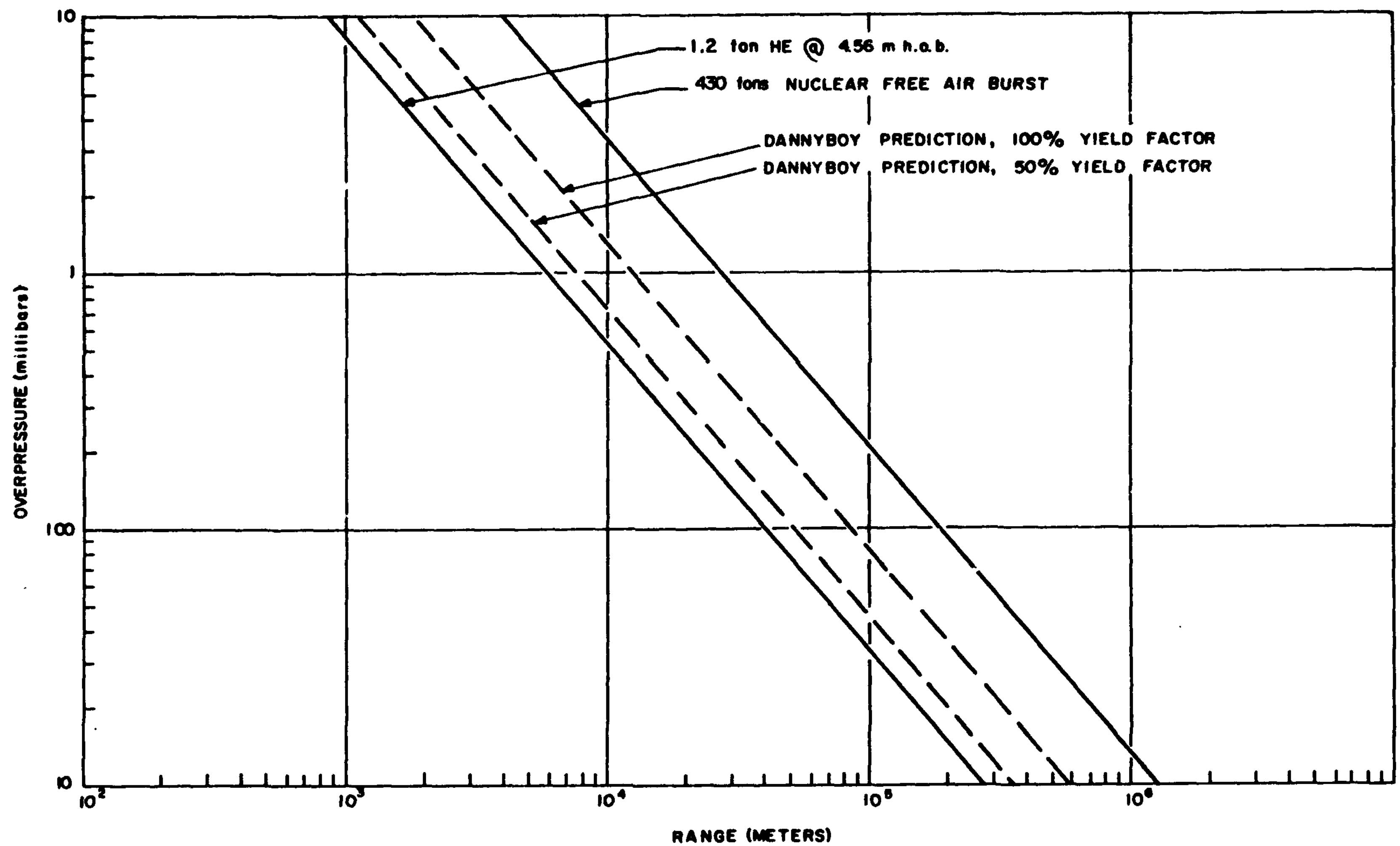

Fig. 1.4 Danny Boy overpressure-distance predictions.

Chapter 2

PROCEDURE

2.1 Shot Participation

Nine microbarograph stations were operated on Danny Boy. Two operated near 7- and 16-km ranges from surface zero to secure data on the transmission coefficient transition between small close-in values and higher factors generally observed at great distance where the signal is carried by ozonosphere sound ducting. A station was in operation at NTS CP-1 (Main Control Point) in Yucca Pass, only because equipment, communications, and an operator were there. A mountain ridge blocked sound propagation into CP-1, but a weak signal could diffract down to the station. Six off-site stations operated at Lund, Caliente, and Boulder City, Nevada, and at Castlecliff, St. George, and Hurricane, Utah.

Locations of microbarograph project interest are shown in Table 2.1. Danny Boy surface zero, HE calibration shot points, and on-site microbarographs were positioned by survey in the Nevada State Coordinate System (NSCS) grid. Off-site stations, except Caliente, had been located in latitude-longitude coordinates by at least third-order survey for previous experiments. The Caliente microbarograph location was estimated from a road map. All locations were converted to NSCS coordinates. In addition, bearings and distances from each shot to each station are shown in the Table 2.1. Values for Lund, St. George, and Boulder City are earth-curvature-corrected for the vector to NTS Station T-1 (full-scale shot point). Curvature corrections were originally calculated from a 1955 first-order survey. Plane trigonometric adjustment was made to Danny Boy and associated HE firing locations.

Planned calibration shots were to bracket Danny Boy at H minus 2 minutes and H plus 3 minutes. A reserve charge was emplaced in case Danny Boy was delayed after the first calibration shot was fired. Safety considerations dictated that this reserve charge be destroyed before postshot re-entry provided it was not required. It was, therefore, scheduled to be detonated at H plus 5 minutes. Added information on signal variability with time would thus be recorded.

Each calibration charge was 1.2-ton uncased HE from surplus at NTS. Charges were made up of 16.3-kg blocks, stacked in an approximate cube. The total weight

TABLE 2.1 MICROBAROGRAPH PROJECT OPERATING SITES AND SHOT-TO-STATION BEARINGS AND DISTANCES*

Microbarograph site	Shot point	Danny Boy	HE Site #3 (H-2 min.)	HE Site #2 (H-hour)	HE Site #1 (H+5 min.)
	Coordinates	N261,989 E179,219	N258,102 E181,139	N258,052 E181,461	N258,358 E181,325
5-Mile	N264,721 E185,539 Z 1,605	066°37' 6,886	033°37' 7,949	031°27' 7,819	033°31' 7,633
Doe Station	N273,014 E191,144 Z 2,325	047°15' 16,242	033°52' 17,958	032°55' 17,823	033°49' 17,643
CP-1	N242,537 E207,024 Z 1,263	124°58' 33,934	121°01' 30,205	121°15' 29,903	121°37' 30,178
Lund	N456,918 E293,510 Z 1,699	031°42' 229,109	030°47' 231,437	030°43' 231,316	030°47' 231,122
Caliente (estimated location)	N316,397 E343,843 Z 1,335	071°43' 173,383	070°17' 172,834	070°14' 172,548	070°21' 172,548
Castlecliff	N254,607 E398,785	091°56' 219,693	090°55' 217,275	090°54' 217,352	090°59' 217,494
St. George	N257,219 E425,980 Z 887	091°06' 246,809	090°12' 244,844	090°12' 244,522	090°16' 244,659
Hurricane	N267,970 E454,820	088°45' 275,667	087°56' 273,860	087°55' 273,541	087°59' 273,666
Boulder City	N135,048 E314,317 Z 750	133°13' 185,379	132°44' 181,325	132°48' 181,054	132°50' 181,362

*Distance in meters.

was the same as had been used for years in NTS blast propagation tests; each calibration charge was equal to four U. S. Navy World War II surplus depth charges. Aircraft operations and fire hazards in Area 18 prevented the firing of cased depth-charge blasts. Charges were stacked 4.56 meters above ground on light wooden platforms for height-of-burst magnification effects. Firing was triggered by hard-wire electrical signal from the Danny Boy firing-sequence control system at the Area 18 Forward Control Point.

Communications were planned to be carried on NTS Off-Site Net 12. Firing tones were to be sent at shot times, and an equipment turn-on signal was planned at H minus 30 seconds. Preliminary voice reports on recording success were to be assembled at H plus 1 hour on this network. In event of radio communication failure, stations were instructed to use telephone communications wherever possible.

2.2 Instrumentation

Microbarograph sensors were Wiancko bourdon tube devices which have been used satisfactorily since 1953 in recording distant air-blast waves from nuclear and HE tests. These were designed to Sandia Corporation specifications and functioned properly according to laboratory tests.[14] New transistorized amplifiers and timers were purchased in early 1960 from the Electronic Engineering Company, Santa Ana, California. Calibration tests show that pressure waves below 15-cps frequency and between 3-μb and 9-mb amplitudes are recorded accurately within ±20 percent for 85 percent of test points.

Stations at CP-1, St. George, and Boulder City were set up in available buildings. All other stations were mounted in carry-all type trucks as mobile units which could be moved from place to place, depending upon the particular experiment being recorded.

Rocket wind measurements were planned. Radar equipment needed for chaff tracking at the Tonopah Test Range (TTR), however, had been moved to the Pacific for Operation Dominic, and the new TTR MPS-25 tracking system could not be readied in time for operation. A description of the rocket wind system is available in the Stagecoach report.[3]

2.3 Data Requirements

Recordings of pressure waves from Danny Boy and from calibration shots were made at all microbarograph stations. Pressure-time Brush recorder pen traces (when successful) were obtained at a paper speed of 2.5 cm/sec and pressure scales which varied from 2 μb/mm to 240 μb/mm, depending on station range from shots. Each set had been calibrated over static pressures ranging from 3 μb to 9 mb. Side-marking pens made 1-second time marks, with distinctive pulses every 10 and 100 seconds. Shot-time radio tones were recorded on one of the pressure-recording pens. When radio communications were poor or out, operators made time marks on records from observation of wrist watches which had been synchronized with WWV time or from a telephoned count-down and time hack from NTS.

Weather data were obtained from the U.S. Weather Bureau Research Station attached to the AEC-Nevada Operations office. Area 18 conditions of surface wind, temperature, and pressure were recorded. Detailed shot-time winds to 2.4 km MSL were measured by pilot-balloon techniques (pibal) and to 5.6 km MSL by radar-tracked (rawin) balloon. Temperature, pressure, relative humidity, and winds were measured to 26.2 km MSL by the rawinsonde station at Yucca Flat.

Chapter 3

RESULTS

3.1 Weather Observations

Surface weather observations from Area 18 at shot time are tabulated in Table 3.1. Pilot-balloon winds near shot time and Area 18 rawinsonde observations are shown in Table 3.2. A radiosonde balloon was tracked from Yucca Flat Weather Station (UCC) to an altitude of 26.2 km where it burst. Winds, temperatures, pressures, and moisture data from this ascension are shown in Table 3.3. Other weather observations were made, but only those pertinent and necessary for sound-ray calculations are given here. Other information, if required, may be obtained from the U.S. Weather Bureau Research Station.

TABLE 3.1 SURFACE WEATHER OBSERVATIONS, AREA 18

Atmospheric pressure.....	832 mb
Temperature..............	+9.7°C
Relative humidity........	27% (from Yucca Raob)
Sky condition............	Overcast at 4 km MSL
Visibility...............	>25 km
Wind direction (from)....	168° (true)
Wind speed...............	6.2 m/sec

Time: 1015 PST March 5, 1962

3.2 Sound Ray Calculations

Troposphere weather data have been used to compute paths of refracted sound to various azimuths of interest. Ray tracing equations [1,7] can be solved by the Raypac computer at NTS CP-1 for field blast prediction, but for more accurate post-analyses, these calculations have been programmed for the CDC-1604 digital computer at Sandia Laboratory. Weather data from Section 3.1 give sound-ray patterns shown in Fig. 3.1, 3.2, and 3.3. In Fig. 3.1, southerly winds with speeds increasing with height give sound ducting toward the northeast quadrant from the surface level up to 4 km MSL. Above this, and up to 6 km, wind direction shifts to a more westerly direction. This causes a complex pattern in the easterly directions (070 and 090°), shown in Fig. 3.2 and 3.3, with a zone of

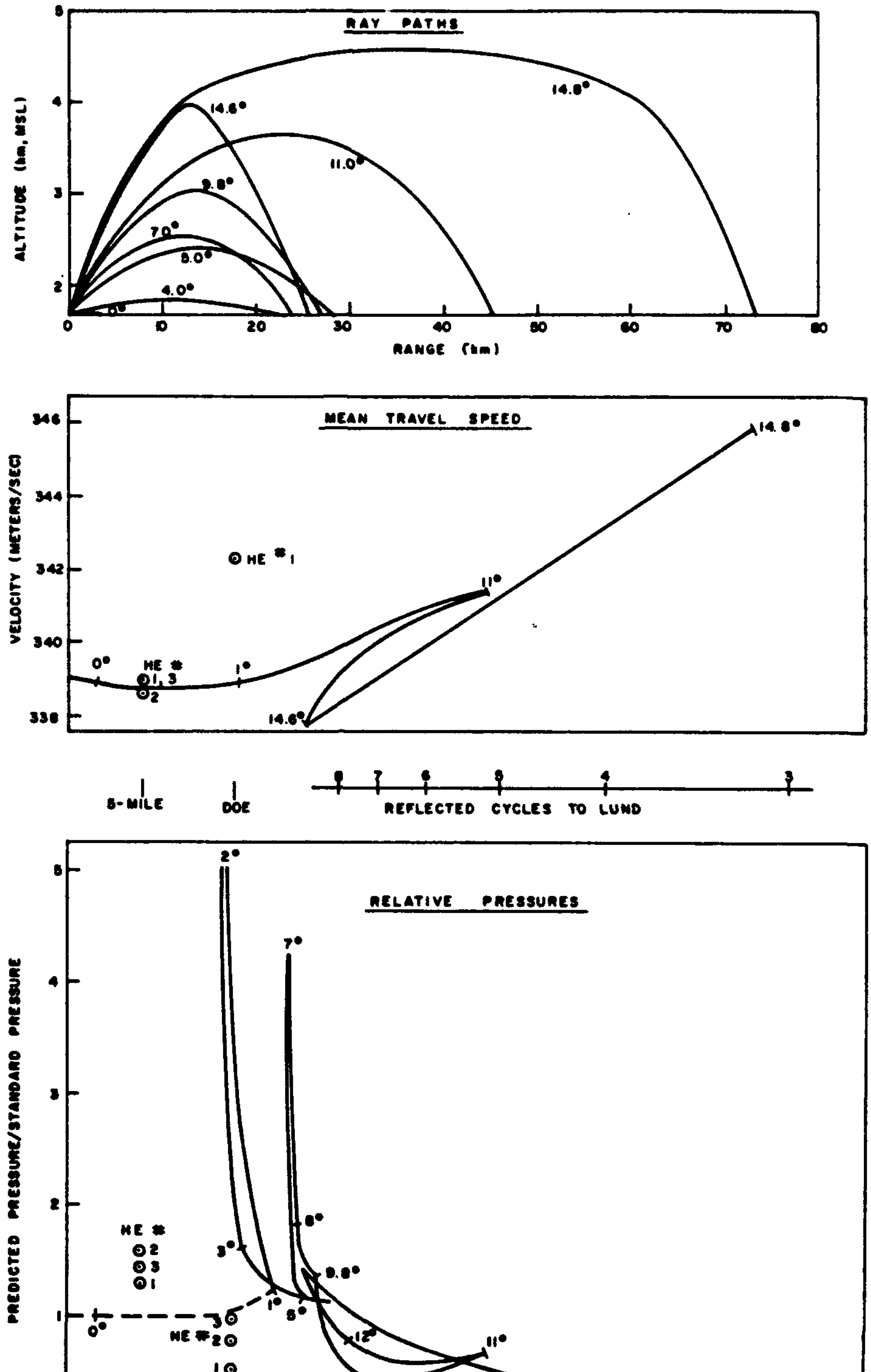

Fig. 3.1 Ray calculations, bearing 032°, propagations to Lund, and HE shot rays to 5-mile and Doe stations. POR-1809-Reed.

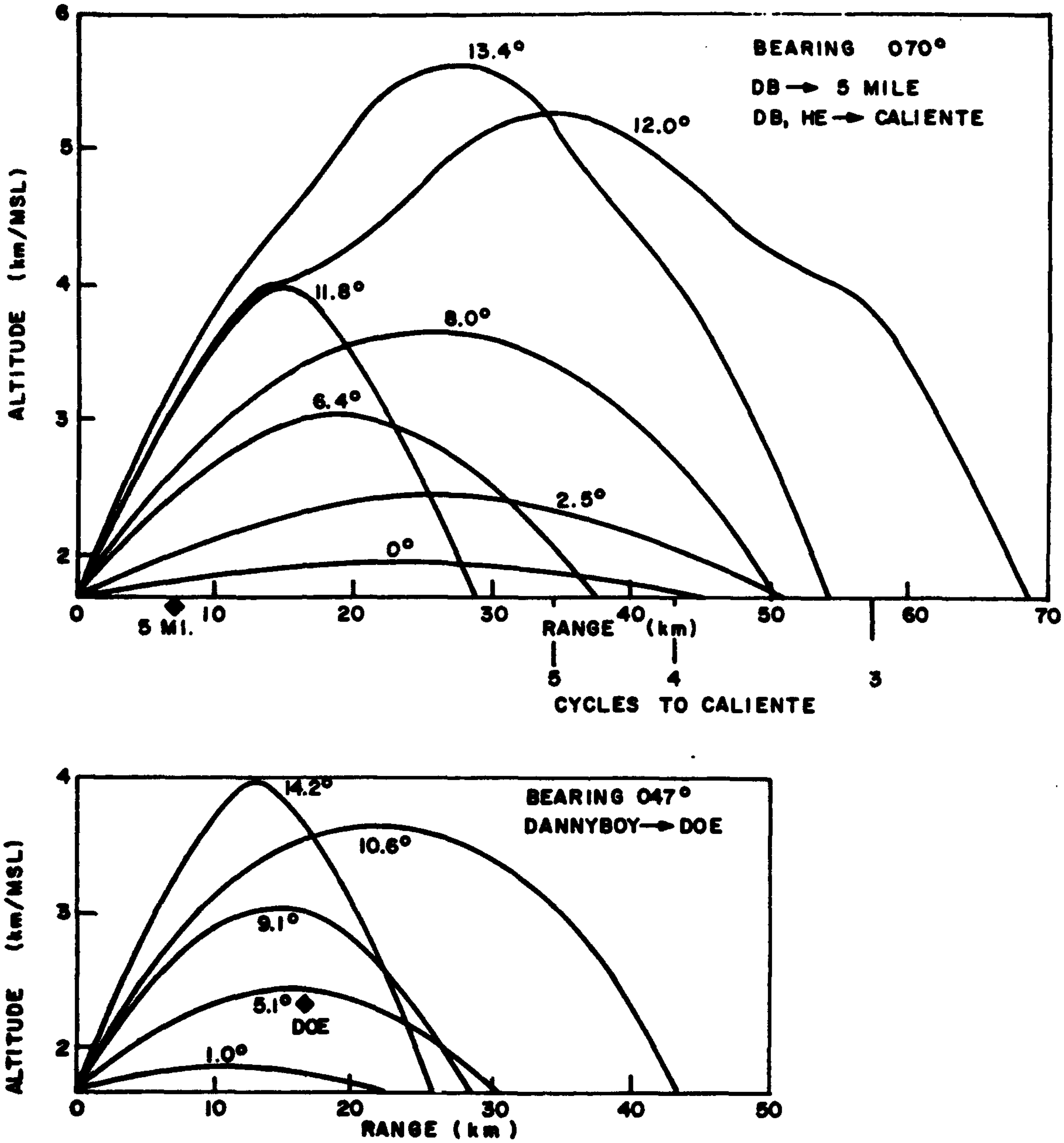

Fig. 3.2 Ray path calculations.

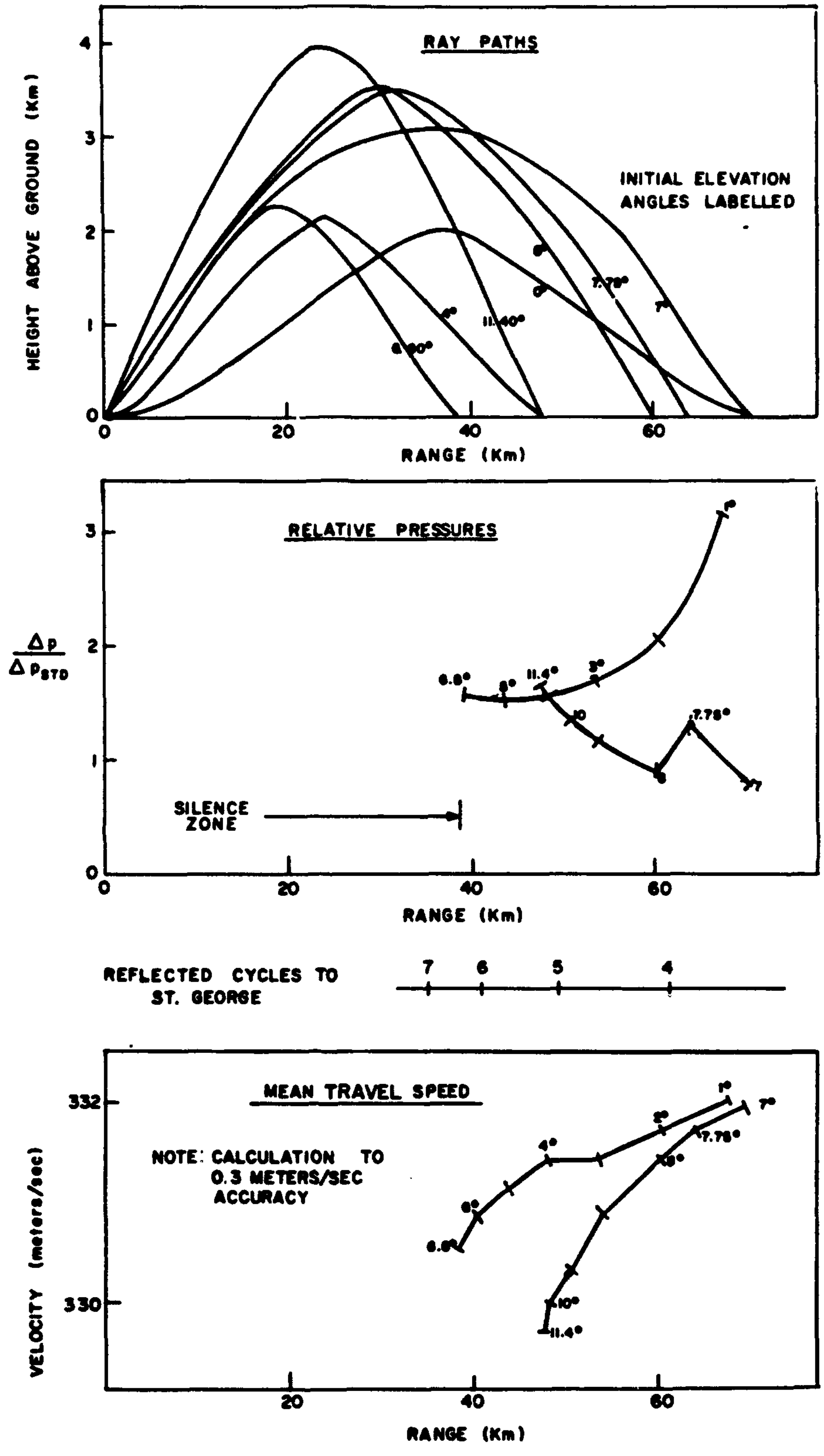

Fig. 3.3 Sound-ray calculations toward St. George.

TABLE 3.2 UPPER AIR OBSERVATIONS, AREA 18

Pibal Winds

Altitude (km MSL)	Direction/Speed (^{o}T.N./meters per sec)	Direction/Speed (^{o}T.N./meters per sec)
Surface	133/ 5.2	168/ 6.2
1.83	140/ 5.7	170/ 6.7
2.13	180/ 6.7	180/ 7.7
2.44	180/11.8	180/10.3
2.74		190/13.9
3.04		190/15.4
3.65		200/19.0
4.26		210/24.2
	Time: 1000 PST	Time: 1025 PST

Rawinsonde

Height (km MSL)	Wind (Deg/meters per sec)	Pressure (mb)	Temperature (^{o}C)
SFC 1.61	168/ 6.2	838	10.2
1.67	170/ 6.2	832	9.7
1.83	171/ 6.7	818	8.7
2.00	173/ 7.7	802	7.4
2.13	178/ 7.7	790	6.1
2.44	184/10.3	762	2.8
2.74	190/13.9	759	2.6
3.04	191/15.4	710	- 1.3
3.27	192/16.0	700	- 2.1
3.31	194/17.0	688	- 3.4
3.35	195/17.5	683	- 3.4
3.65	199/19.1	658	- 3.5
3.70	200/22.2	654	- 3.5
3.96	202/23.7	635	- 4.6
4.26	206/24.2	610	- 6.3

Time: 1025 PST

TABLE 3.3 RAWINSONDE REPORT

Upper Air Data

Height (km MSL)	Wind (Deg/meters per record)	Pressure (mb)	Temperature (°C)	Dew point (°C)	Relative humidity (%)
SFC 1.20	calm	881	6.9	- 2.8	50
1.22	calm	877	6.9	- 3.4	48
1.39	167/ 2.6	860	7.0	- 10.3	28
1.49	167/ 1.5	850	6.3	- 11.3	27
1.52	170/ 3.6	845	6.1	- 11.5	27
GZ 1.67	179/ 7.2	832	5.3	- 12.2	27
1.83	181/ 7.7	815	4.3	- 13.0	27
2.13	188/10.8	784	2.3	- 15.7	25
2.44	189/13.9	757	0.3	- 18.9	22
2.74	190/14.9	727	- 1.7	- 21.2	21
2.88	196/11.3	716	- 2.4	- 21.8	21
3.04	198/13.9	701	- 3.0	MB	MB
3.04	198/14.4	700	- 3.0	MB	MB
3.35	199/13.9	674	- 5.5	MB	MB
3.54	192/15.5	657	- 7.5	- 25.6	22
3.65	191/16.0	647	- 7.6	- 16.2	50
3.70	191/17.0	644	- 7.7	- 14.5	58
3.96	194/20.1	624	- 7.5	- 11.7	72
3.97	194/20.1	623	- 7.5	- 11.3	74
4.26	199/22.7	598	- 9.1	- 12.5	76
4.57	200/26.3	576	- 10.7	- 13.8	78
4.61	202/26.3	572	- 10.9	- 14.0	78
4.87	211/25.8	552	- 12.6	- 15.6	78
5.18	216/23.7	532	- 14.5	- 17.6	77
5.48	225/25.8	511	- 16.5	- 19.8	76
5.64	228/26.3	500	- 17.6	- 20.8	76
5.79	230/25.8	491	- 18.5	- 22.1	74
6.09	231/23.2	470	- 20.7	- 24.1	74
6.21	231/21.1	462	- 21.4	- 24.8	74
6.39	230/20.6	452	- 22.6	- 26.3	72
6.70	232/23.7	433	- 24.6	- 28.5	70
7.00	229/24.7	409	- 27.4	- 31.5	68
7.27	225/25.2	400	- 28.5	- 32.7	67
7.31	223/25.2	398	- 28.8	- 33.3	65
7.61	220/26.9	380	- 31.5	- 36.4	62
7.92	220/28.3	366	- 33.9	- 39.1	60
8.22	223/28.3	350	- 36.3	- 41.5	59
8.25	222/28.3	348	- 36.8	- 42.0	59

Yucca Weather Station, 1015 PST, March 5, 1962

TABLE 3.3 RAWINSONDE REPORT

Upper Air Data

Height (km MSL)	Wind (Deg/meters per record)	Pressure (mb)	Temperature (°C)	Dew point (°C)	Relative humidity (%)
GZ 8.53	224/28.3	334	- 39.5	- 44.5	59
8.58	224/27.8	332	- 40.0	- 45.0	59
8.83	225/27.8	319	- 42.6	-	-
9.13	226/27.8	306	- 45.1	-	-
9.26	225/28.3	300	- 46.3	-	-
9.97	230/31.4	269	- 53.2	-	-
10.33	238/32.4	254	- 55.9	-	-
10.44	240/32.4	250	- 56.1	-	-
10.66	242/34.0	242	- 56.8	-	-
11.74	243/36.1	203	- 59.9	-	-
11.85	244/36.1	200	- 59.8	-	-
12.18	243/34.0	189	- 59.4	-	-
13.39	244/29.9	156	- 58.5	-	-
13.65	244/30.4	150	- 58.6	-	-
13.70	244/29.9	148	- 58.6	-	-
14.14	243/30.9	139	- 58.7	-	-
14.37	243/33.0	134	- 59.9	-	-
14.90	244/32.4	123	- 59.9	-	-
15.22	248/30.4	115	- 61.6	-	-
15.47	251/28.3	112	- 63.0	-	-
16.16	264/24.7	100	- 64.0	-	-
16.75	255/22.7	91	- 64.8	-	-
17.67	252/20.1	78	- 66.0	-	-
18.17	258/14.9	72	- 62.3	-	-
18.27	260/14.4	71	- 62.4	-	-
19.70	276/17.5	56	- 64.7	-	-
19.79	275/18.5	55	- 63.5	-	-
20.05	278/18.0	53	- 61.5	-	-
20.40	283/16.0	50	- 62.0	-	-
20.66	288/13.4	48	- 62.3	-	-
21.31	294/12.9	43	- 60.9	-	-
22.29	296/14.9	37	- 58.9	-	-
22.84	293/16.0	34	- 57.3	-	-
23.60	292/14.9	30	- 55.1	-	-
24.36	294/14.4	27	- 53.0	-	-
25.88	290/15.5	21	- 48.9	-	-
26.23	-	20	- 48.0	-	-

Yucca Weather Station, 1015 PST, March 5, 1962

silence extending to 30 or 40 km range, followed by a sound ring reaching to 70 km. This ray pattern is reflected by the ground and repeated to longer ranges. Distances to long-range stations divided by integers are plotted to show the number of reflected cycles of the sound pattern required to reach each station.

For example, on the 070° bearing in Fig. 3.2, a sound ray emitted at 13 degrees elevation angle, would strike near Caliente after 3 cycles of travel and two ground reflections. An 11-degree ray would hit near Caliente after 5 cycles through the atmosphere, traveling up to nearly 4 km MSL in each cycle, and be reflected four times by the ground.

Calculations for ozonosphere propagations were not attempted since there were no rocket wind observations made at Tonopah nor at either the Pacific Missile Range (PMR) at Point Mugu, California or at White Sands Missile Range (WSMR), New Mexico, on the Danny Boy shot date.[15] At WSMR on March 2, two Arcas rocket-launched parachute-track wind observations showed generally westerly winds with speeds increasing gradually from 20 knots at 80,000 feet MSL to 115 knots at 175,000 feet MSL. On March 9, a PMR Hasp II radar chaff rocket observation showed nearly the same flow pattern; the wind speed, however, at 175,000 feet MSL was 136 knots. There was a small wind component blowing from the south on each of these observations.

It would probably be valid to use either of these rocket winds for an ozonosphere sound propagation calculation for Danny Boy but neither would be adequate for detailed verification. In general, however, these winds indicate that moderately strong ozonosphere sound ducting would be directed eastward.

3.3 Blast Pressure Measurements

Danny Boy was fired at 1015 PST, after a 15-minute delay which was announced within the last preshot hour. The H-2 minute calibration shot fired on schedule at 1013 PST, and the firing signal was transmitted on Net 12 Radio. The H minus-30-second radio tone was sent out on schedule. At Danny Boy firing, no radio tone was transmitted. Also, for a yet undetermined reason, the calibration shot scheduled for H plus 3 minutes was fired at zero time; consequently, a firing

signal was transmitted at H plus 3 minutes but no shot was fired. At H plus 5 minutes, 1020 PST, the last calibration shot was fired, but no firing signal was transmitted to Net 12. Results are summarized in Table 3.4. Although the H-plus-0 HE fired at Danny Boy time, the two sites were spread, and there was no difficulty in identifying signals except at Lund.

During the night before the shot, the Highland Peak radio repeater station experienced transmission failure, and off-site stations in the northeast and east lost radio contact. The 15-minute delay in firing could not be telephoned to some remote sites. Each station, however, did manage to be "on" at signal arrival times. At Castlecliff and Hurricane, local winds caused ambient noise of 60- to 100-μb amplitudes that obscured any signal which might have been recorded.

Difficulties with equipment at Caliente prevented recording at the time the operator believed the signals were to arrive. The station, however, was running at the correct time of arrival of the actual shot signals, and the recording showed readable deflections separated by correct time intervals. The operator did not, however, have a sufficiently accurate time base to establish whether the recorded signals propagated in a troposphere wind-generated sound duct or in the ozonosphere sound duct. His unsynchronized wristwatch time-base arrivals are given in Table 3.4. These indicate that recorded signals were ozonosphere-ducted. If the operator's watch were as much as one-minute in error (not unlikely), these signals may have been ducted by tropospheric winds near 5.5 km MSL as shown in Fig. 3.2.

At Lund wristwatch timing was poor and rumbles from Danny Boy, H plus 0, and H minus 2 HE from troposphere and ozonosphere paths could not be positively separated. Only the maximum amplitude recorded signal for Lund is entered in Table 3.4.

Good records were obtained from all shots by the St. George station. Ambient wind noise varied only from 2- to 6-μb amplitudes. A troposphere duct signal (Signal A in Table 3.4) was recorded to confirm the ray pattern shown in Fig. 3.3. It was followed later by three bursts (B, C, and D) of more slowly arriving noise signals channeled by the low ozonosphere. Signal correlations between Danny Boy and the H-minus-2- and H-plus-0-minute (different distance) shots are good. At H plus 5 minutes, the ozonosphere signal record pattern had changed appreciably, and, at most, only an infinitesimal troposphere signal could be detected.

TABLE 3.4 MICROBAROGRAPH DATA SUMMARY

Station	Signal	Shot Time	Danny Boy 1015 PST	HE No. 1 1013 PST	HE No. 2 1015 PST	HE No. 3 1020 PST
5-Mile	-	t_a	20.32	23.45	23.07	22.52
		$\bar{V}$	1112	1112	1111	1112
		P_k	203	1270	1572	1444
		F	-	1.303	1.585	1.420
		T	0.01956	-	-	-
Doe	-	t_a*	46.75	52.41	51.24	53.65
		$\bar{V}$	1140	1123	1140	1077
		P_k	112	181	273	349
		F	-	0.521	0.779	0.982
		T	0.0617	-	-	-
CP-1	-	t_a	111.8*	97.13	95.12	96.44
		$\bar{V}$	995*	1020	1030	1027
		P_k	14.3	17.9	17.1	16.0
		F	-	0.0892	0.0844	0.0797
		T	0.155	-	-	-
Caliente	-	t_a	570	567	567	567
		$\bar{V}$	995	997	994	994
		P_k	15.11	17.60	12.24	15.50
		F	-	0.712	0.496	0.627
		T	0.161	-	-	-
St. George	A	t_a	757	749	748	747
		$\bar{V}$	1066	1070	1070	1071
		P_k	12.63	11.80	16.57	1.24
		F	-	0.701	0.985	0.074
		T	0.1696	-	-	-
	B	t_a	776	771	771	770
		$\bar{V}$	1040	1039	1039	1040
		P_k	6.62	5.59	4.97	19.44
		F	-	0.332	0.295	1.156
		T	0.1825	-	-	-

*Inaccurate t_a and $\bar{V}$; cause unknown.

TABLE 3.4 MICROBAROGRAPH DATA SUMMARY

Station	Signal	Shot Time	Danny Boy 1015 PST	HE No. 1 1013 PST	HE No. 2 1015 PST	HE No. 3 1020 PST
St. George (cont)	C	t_a	790	784	782	782
		$\overline{V}$	1021	1022	1022	1022
		p_k	4.97	5.38	5.38	5.80
		F	-	0.319	0.319	0.345
		T	0.1480	-	-	-
	D	t_a	793	787	785	786
		$\overline{V}$	1018	1018	1019	1019
		p_k	6.41	18.21	9.32	12.00
		F	-	1.081	0.553	0.713
		F	0.0971	-	-	-
Boulder City	A	t_a	630	617	616	617
		$\overline{V}$	966	965	965	965
		p_k	18.68	32.60	16.30	35.20
		F	-	1.330	0.665	1.438
		T	0.1579	-	-	-
	B	p_k	17.82	46.50	37.40	29.35
		F	-	1.898	1.527	1.198
		T	0.0786	-	-	-
	C	p_k	20.00	20.20	20.85	34.35
		F	-	0.824	0.851	1.400
		T	0.1530	-	-	-
Lund	-	p_k	-	39.4 Max	-	-
		F	-	2.355	-	-
	Other signals not identified without time base.					
Castlecliff	No signals identified; wind noise 60-100 μb.					
Hurricane	No signals identified; wind noise 60-100 μb.					

Symbols:
- t_a - Signal arrival time, seconds after shot
- $\overline{V}$ - Average signal velocity, distance/arrival time
- p_k - Peak-to-peak pressure, microbars
- F - Ratio of observed pressure to IBM-M scaled pressure
- T - Ratio of observed pressure to expected pressure from 420-ton nuclear free air burst

At Boulder City, the first HE shot produced a good signal record from ozonosphere propagation and a possible troposphere-ducted signal, although ray calculations do not predict one. No troposphere signal was discernible from Danny Boy or the H-plus-0 HE shot, but momentary gusty wind noises at the appropriate arrival time may have obscured them. Clear ozonosphere signals were recorded from both Danny Boy and the H-plus-0 HE shot. The HE shot at H plus 5 minutes gave a possible weak troposphere signal and a good ozonosphere signal. Three cycles of ozonosphere signal readings (A, B, and C) are entered in Table 3.4, with arrival time entered only for the first cycle. The other cycles were recorded within 5 seconds.

Good records were made of all shots at the Area 18 and Doe stations. Weak but readable signals were recorded at CP-1.

All pressure measurements, including tentative Ballistic Research Laboratories close-in data, are plotted against the distance coordinate in Fig. 3.4. All Danny Boy pressures fall well below the curve for HE calibration shots, where reference to Fig. 1.4 shows that larger pressures were expected. Records from HE shots fall reasonably close to the curve predicted for homogeneous atmosphere transmission. The amount by which Danny Boy data fell below HE calibration shot data appears to decrease with distance, generally confirming the increased transmissivity at long range shown in Fig. 1.1.

With each signal recorded in Table 3.4, there is a factor listing the signal amplitude ratio to the scaled IBM Problem M pressure predicted for homogeneous atmosphere propagation from Eq. 1.5 and corrected for ambient pressure at the microbarograph elevation. Sound ducting shown in Fig. 3.1 cause the relatively strong signals recorded at the 5-mile station. Lower relative amplitudes recorded at Doe station may have resulted from local terrain interference or from changes in the detailed weather structure. These weather changes are responsible for the nearly factor-of-2 difference in amplitude between the H-minus-2 and H-plus-5-minute HE shots. Calculation predicted no sound ducting toward CP-1 (or Boulder City), but small tropospheric propagations were recorded from each shot. The slow velocity and small amplitude of these propagations indicates that they were probably diffracted down from wave rays traveling overhead near 7 or 8 km MSL.

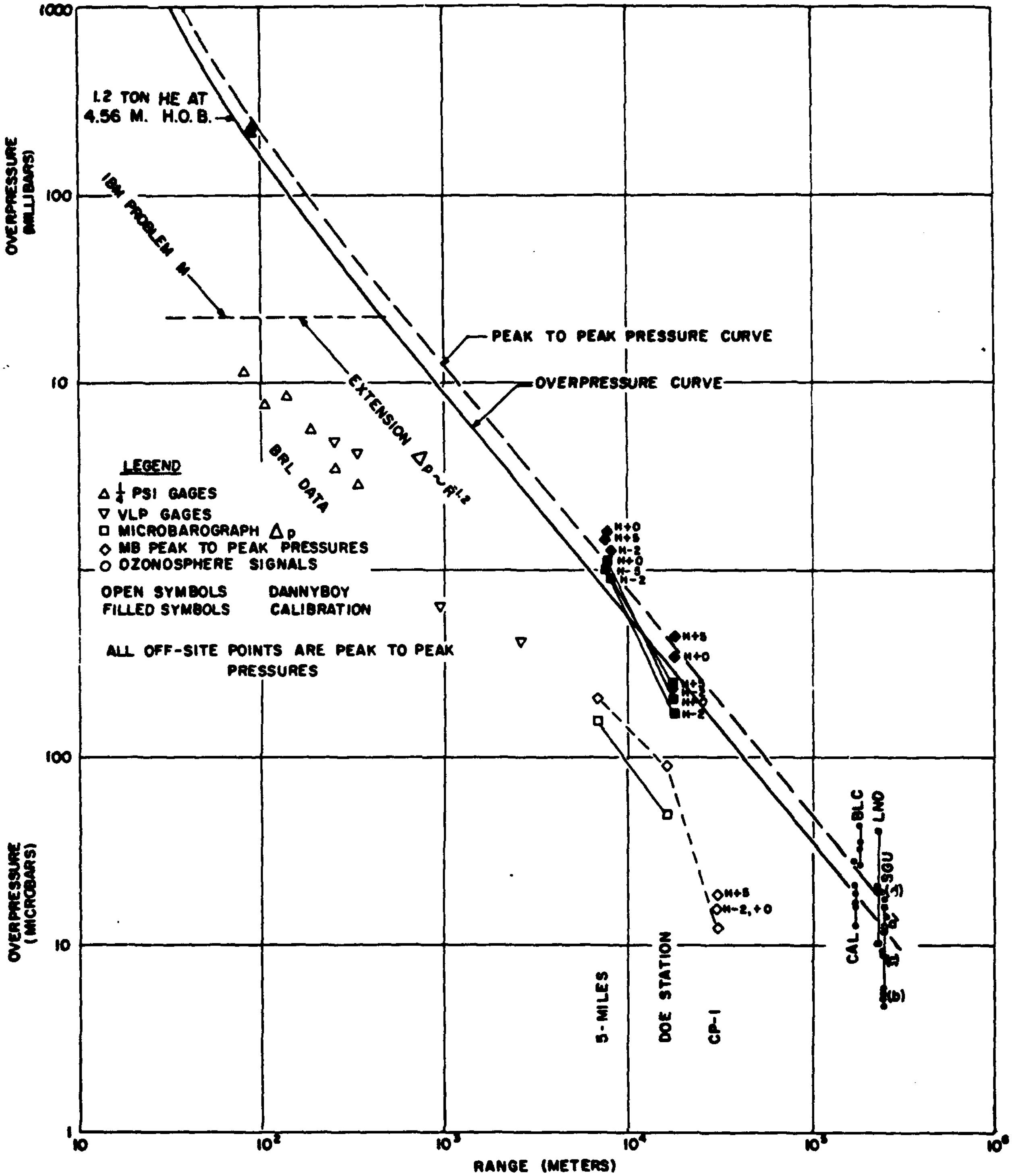

Fig. 3.4 Danny Boy microbarograph data.

The strongest relative propagation was recorded at Lund, which was consistent with the small southerly component of ozonosphere winds reported by PMR and WSMR rocket observations[15] described in Section 3.2. Nearly as strong signals were recorded at Boulder City, however, which establishes that details of focusing patterns and ranges are more important in blast prediction than dependence on general wind directions and speeds. Usually stronger signals are reported at St. George than at Boulder City or Lund, but in this experiment, St. George results were generally weaker than normal. This was probably a result of ozonosphere focusing being centered at some distance from St. George. It is regrettable that at both Castlecliff and Hurricane local surface winds were too strong to allow determination of actual caustic range.

Transmissivity values for Danny Boy in Table 3.4 were computed as follows: Each signal (A, B, C, or D) relative amplitude logarithm was weighted in inverse proportion to the square root of time separation from Danny Boy. Time separations for HE Nos. 1, 2, and 3 were 120, 6, and 300 seconds, respectively. The HE No. 2 separation time was estimated from a distance separation equivalent. Weighting factors used were 0.164, 0.733, and 0.103. Assumed time dependence follows from the fact that turbulent wind variations increase in proportion to the square root of observation separation times, and wind-affected propagation repeatability may well decrease at a similar rate.

Logarithmic averages of signal transmissivities for each station are listed in Table 3.5, together with a logarithmic off-site average transmissivity of 0.140. Equal weighting was used in each of these averaging calculations. This overall transmissivity, equivalent to a factor-of-7 attenuation, is only weakly affected by weighting and log averaging procedures.

Off-site transmissivities for Danny Boy and other underground tests are compared in Fig. 3.5. Data from Danny Boy fall, in general, near other Plowshare excavation test data points. Scaled depths of burst for nuclear shots are calculated from the assumption that nuclear blast production is equal to production from half the yield of HE which, of course, is of known validity for atmospheric bursts but is a questionable assumption in cratering or underground tests. If, however, NE = HE were assumed, it would merely shift all nuclear data points to

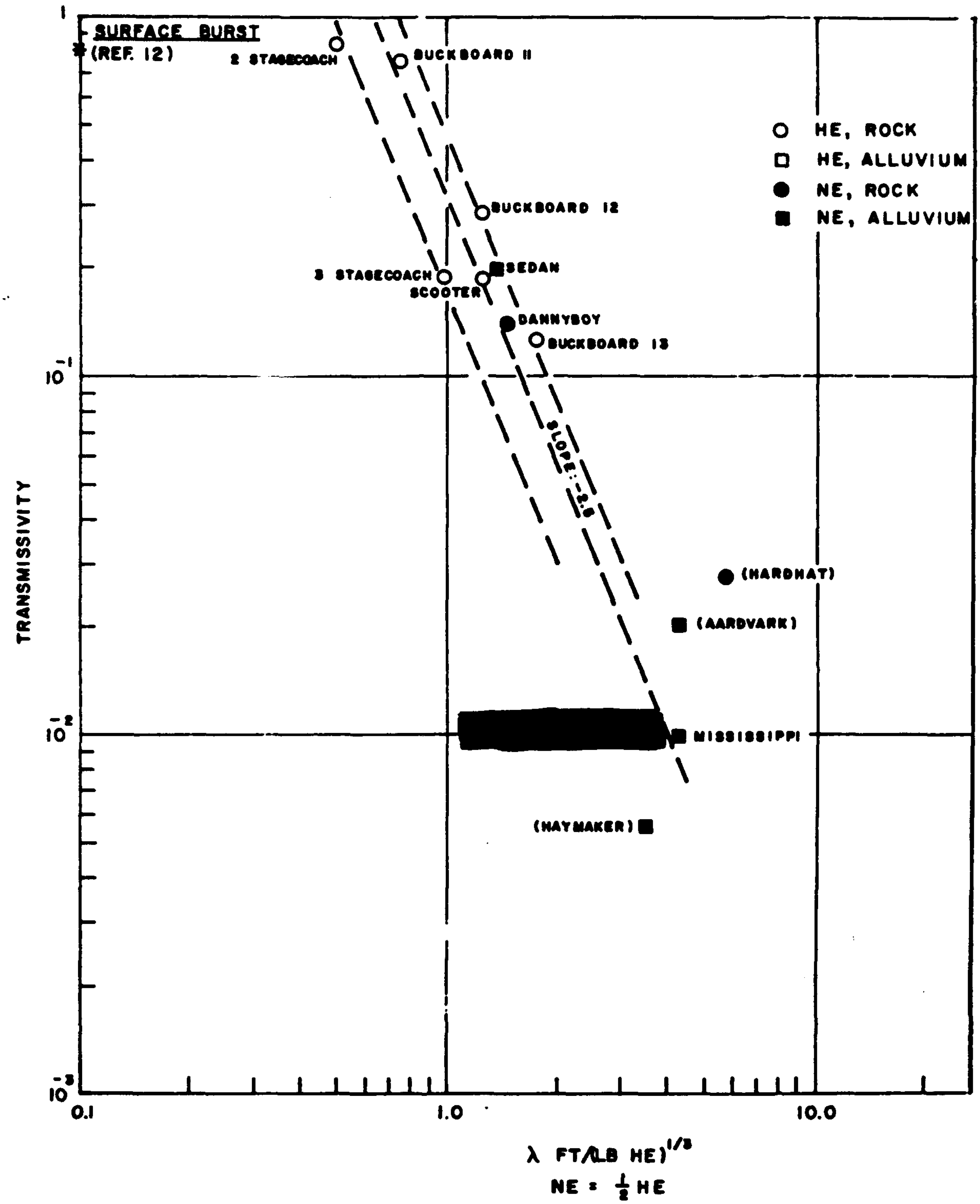

Fig. 3.5 Off-site transmissivities.

1/1.26 of the indicated scaled depth of burst. Conclusions from comparisons or extrapolations to larger excavators would not be seriously affected.

TABLE 3.5 DANNY BOY BLAST TRANSMISSIVITY SUMMARY

Station	Signal A	Signal B	Signal C	Signal D	Station Average
<u>On-site</u>					
5-Mile	0.01956	-	-	-	0.01956
Doe	0.0617	-	-	-	0.0617
CP-1	0.155	-	-	-	0.155
<u>Off-site</u>					
Caliente	0.161	-	-	-	0.161
St. George	0.1696	0.1825	0.1480	0.0971	0.144
Boulder City	0.1579	0.0786	0.1530	-	0.124
Off-site average					0.140

Points shown for Hardhat, Aardvark, and Haymaker were not determined with comparable accuracy to other points. High surface winds severely interfered with microbarograph measurements of these tests. It appears that comparable yields burst in the same medium give transmissivities which decrease about in proportion to the 2.5 power of scaled burst depth, or $f \approx \lambda^{-2.5}$. [redacted] Data or theories to establish transmissivity factors in extrapolated regimes are as yet inadequate.

Chapter 4

SUMMARY

Air blast measurements were satisfactorily made at three stations at the Nevada Test Site to establish that transmissivity from Danny Boy increased from 2 percent at 7 km to 16 percent at 34 km range. Off-site transmissivities were obtained at three stations to indicate a 14 percent average at ranges from 175 to 250 km; i.e., blast-pressure amplitudes from Danny Boy were 14 percent as large as would have been recorded from the same yield, free-air-burst at the same time. One station record was useless for correlations because of a partial communications failure. At two stations strong local surface winds caused ambient noise levels which were considerably in excess of signal strengths.

Since ozonosphere winds could not be measured during this project, high-altitude propagation predictions could not be calculated by ray-tracing techniques.

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